Giotto Ion Mass Spectrometer Measurements at Comet P/Grigg-Skjellerup

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Abstract

‘l’he Giotto Ion Mass Spectrometer High Intensity Spectrometer (IMS-HIS) measured fluxes of ions from about 260,000 km before (10:08:37 UT spacecraft time) to about 86,000 km after (17:01:33 UT spacecraft time) closest approach to comet P/Grigg-Skjellerup during the encounter on July 10, 1992. Although the HIS sensor was not designed to measure protons, the unusual flyby geometry at Grigg-Skjellerup allowed the sensor to detect these ions. Considerable temporal structure appears in the data, well-correlated with the data of other instruments onboard, especially those of the magnetometer. In particular, the proton count rate correlates with the direction of the magnetic field. The strong modulation of the count rate at the water group ion cyclotron period (~90 s) inside the inbound bow wave indicates a very narrow proton pitch angle distribution. Hence at Grigg-Skjellerup, the protons appear to experience very little pitch angle scattering.

1. INTRODUCTION

The Giotto spacecraft made its second comet encounter on the afternoon of July lo, 1992 when it flew within about 200 km of comet P/Grigg-Skjellerup (G-S). Many of the instruments onboard were. still operational, and the. results of measurements by some of them have already been reported (e.g. *Coates et a/,* [1993], *Johnstone et al., [1993], Levasseur-R egourd et al., [* 1993], *McDonnell et al., [1993], McKenna-Lawlor et al., Neubauer et al., [1993],* and *Pätzöld et al., [1993]).* In this paper we describe and discuss results of measurements by the High Intensity Spectrometer (HIS) sensor of the Giotto Ion Mass Spectrometer (IMS) during the encounter. The IMS has been described in detail previously [*Balsiger et al.,* 1987], but in the next section below we discuss those aspects of the instrument especially pertinent to the present measurements. The relation of the HIS measurements to those of other onboard instruments, particularly to those of the magnetometer, are also discussed.

2. THE ION MASS SPECTROMETER

The Giotto IMS consists of two separate sensors, the High Energy Range Spectrometer (HERS) and the 111S, already mentioned. The HERS was damaged during the Halley flyby and was not functioning at G-S. All the results discussed here are therefore from the HIS. This sensor was designed to measure the cold, nearly stagnant plasma close to comet Halley, and consists of two separate systems, the "mass analyzer" (MA) and the "angle analyzer" (AA). The MA involves both magnetic and electrostatic sections, providing true mass analysis. The geometry, magnetic field strength, and voltage steps for this analyzer were selected to provide a mass/charge range capability of 12 to 56 amu/e at the nominal Giotto-Halley flyby speed of 68 km/s (which, for stagnant plasma is therefore the flow speed relative to the spacecraft) [*Balsiger et* al., 1987 and *Altwegg et al.*, 1993]. The energy range corresponding to this mass/charge range and velocity is approximately 300 to 1400 eV/e and is covered by 64 voltage steps. At flow speeds significantly different from this value, the mass/charge range is shifted inversely relative to the speed change, but since the MA involves momentum as well as energy selection, determining the shift is not straightforward, So, at the G-S flyby speed of 14 km/s, it is expected that the mass/charge range is shifted well above those of the most abundant ions.

Not surprisingly, therefore, there were no ion counts observed by the MA above the background level of a few counts per 4s spacecraft spin during the entire G-S encounter. We shall return to this point later. All measurements described in this paper, then, were obtained with the HIS AA [*Kettman et al., 1990,* and *Goldstein et al.*, 1992]. This system consists of a curved plate electrostatic analyzer, using the same voltage program of 64 quasi logarithmic steps as for the MA. This also gives a mass/charge range of 12 to 56 amu/e for the nominal Halley flyby speed of 68 km/s. Again, this translates to an energy/charge range of about 300 to 1400 eV/e. However, since this is simply an electrostatic analyzer, with no momentum selection as in the case of the MA, the AA will respond to any mass/charge ions in this energy/charge range. This is an important point to understand in order to interpret the measurements.

The AA field of view (FOV) is divided into 5 approximately equal, adjacent angular fans, shown schematically relative to the spacecraft main features in Fig. 1 (which is not to scale). Each fan is approximately 5° wide in the plane of the Figure (which includes the spin axis) and 2° normal to this plane. Note also that AA #l includes the spin axis. The spin of the spacecraft thus sweeps these fans through a full cone of 22° half angle, with no gaps, with axis coincident with the spin axis. During the Halley encounter the spacecraft velocity vector was closely aligned with the spin axis. Hence the HIS was sensitive to the cold ions relatively stationary with respect to the comet, being swept into the sensor by the spacecraft motion at 68 km/s. The capability of the f 11S field of view to look past the front edge of the spacecraft is achieved by use of a pair of flat electrostatic deflector plates in front of the instrument aperture, with the plane of the plates parallel to the spacecraft surface. A low voltage across the plates deflects ions traveling parallel, or nearly so, to the spin axis into the instrument aperture. The purpose of this feature, designed for the Halley encounter, was to prevent the sensor aperture from looking directly into the flux of cometary dust. Angular resolution of 22.5° in the spin, or azimuth direction is obtained by the IMS data processor dividing each spin into 16 equal bins. The HIS does a full measurement of all parameters in each 4s spin; hence this is the time resolution of the sensor.

Because of telemetry rate limitations, only the ion counts from AA1 and the sum of counts for AAs 2-5 were downlinked on a regular basis. Individual AA count rates were sent back only for selected energy steps, corresponding to the water group (i.e. mass/charge 17-19 amu/e), 28 and 44 amu/e at the Halley flyby speed. These correspond also to the azimuth angle data transmitted, so detailed azimuth angle distributions are available only for the selected energy steps. This will be discussed later in more detail in relation to the G-S measurements.

3. FLYBY GEOMETRY

The geometry of the encounter was somewhat unusual, especially from the point of view of the HIS field of view, so we will spend some time describing the important features. Details have already been given by *Neubauer et al. [1993]*, who also described the unusually high interplanetary magnetic field at the time of the encounter. In a comet-sun-ecliptic (CSE) reference frame, with the comet at the origin, X pointing from the comet to the sun, Y in the ecliptic plane pointing opposite to planetary motion, and Z completing the right hand system (and thus pointing north), the velocity components of Giotto at encounter were -2.60, 5.03, -12.8 km/s (which gives a total speed of 14.0 km/s). Thus the motion was largely from north to south, mainly in the Y-Z plane. Furthermore, the spacecraft spin axis at this time was along the Y-axis. The projection of this trajectory on the Y-Z plane is shown in Fig. 2. Also shown, schematically, is the 22° half cone angle FOV of HIS swept out by the spacecraft spin (right-handed with respect to the Y-axis). Note thus that with this encounter geometry the cold, stagnant ions (with nominal velocity $-V_{S/C}$) for which HIS was designed, have no direct access to the sensor. Nevertheless, throughout the encounter HIS did measure an ion flux. We describe next the characteristics of the measurements, and following this give our interpretation in terms of cometary processes.

4. THE HIS MEASUREMENTS

Figure 3 shows a plot of the sum of the 5 AA sensor counts/spin for each 4s spin from 260,000 km before to about 86,000 km past closest approach (CA). This corresponds to about 10:08:37 to 17:01:33 UT SCET (spacecraft event time), assuming a 13.99 km/s spacecraft velocity and CA at 15:18:43 SCET. The background count rate. of the HIS sensor is typically a few counts/spin or less, and has been ignored here. The ratio between the AA1 counts and the total AA counts varied between about 0.2 and 0.3 throughout the encounter, but not in any apparently consistent manner. We therefore consider only the sum from all 5 detectors. The location of the inbound bow wave (BW) as well as the outbound bow shock (BS), as identified by *Neubauer et al. [1993],* are shown for reference.* There are a few gaps when data were bad or missing. Of note are the following features of this plot: 1) the approximately steady baseline of about 30 counts/spin both before and after the encounter, 2) the increase in countrate around CA, 3) the asymmetry of the variations relative to CA, and 4) passage through the bow shock/wave is not obvious from the count rate, although inbound the count rate does increase just after passage. Some of this is more evident in Fig. 4, which shows a portion of the same data on an expanded scale, beginning just before passage through the inbound bow wave. The additional striking feature in this Figure is the quasi periodic modulation of the count rate, with a period of about 80-100 s. Previous reports of plasma measurements at G-S by the Giotto Johnstone Plasma Analyzer (JPA) [*Johnstone et al.,* 1992, *Huddleston et al.,* 1993, and *Coates, et al., 1993]* have not shown this modulation

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* There is some controversy in the literature on whether the inbound feature is a true shock; we adopt here the identification by *Neubauer et al. [* 1993] that this is not a true shock, and refer to it as a "bow wave,

in measured flux, at least partly because the measurement cycle used by JPA has a time resolution of 128 s. We shall return to this later

Well before CA, say farther from the comet than 40,000 km, the fluctuations in the counts/spin shown in Fig. 3 are within simple $\sqrt{n}$ statistics, so we do not believe that those fluctuations have a physical significance.

Energy spectra for three regions of Fig. 3 are shown in Fig. 5. These intervals are chosen to correspond to well before CA (solid line), an approximately equal distance interval just before inbound bow wave passage (dashed line), and a shorter interval covering the period of greatest count rate, from just inside the bow wave to the outbound shock (dotted line). Each plot gives the number of counts summed in the interval, in each of the 64 energy bins, normalized by the number of spins in the interval. Divided up into 64 bins, the count rates are quite low, but by summing over a large number of spins, there is not a great deal of scatter. Surprisingly, throughout the encounter, the measured count rate covered the full energy bandpass of HIS. The distribution in count rates far from the comet and those in what might be called a "foreshock" region are very flat with energy, with only a slight enhancement for the latter relative to farther out from the cornet. The spectrum inside the cometary region proper, however, shows about a 50% increase over the earlier spectra, with a clear enhancement just above 400 eV/e. Note that the geometric factor of HIS is energy dependent in a way that would show an approximately inverse falloff in equivalent ion flux with increasing energy. Unfortunately, we cannot say a great deal quantitatively about the equivalent incident flux of ions under these conditions; we return to this subject below.

Plots of the angular dependence of the counts/spin in the azimuth (spin) plane for the same three intervals are shown in Fig. 6. The plane of the Figure corresponds to the X-Z plane, with +Y coming out of the page, The angles are arbitrarily measured such that 0° corresponds to the outward normal from the spacecraft surface at the HIS sensor pointing along -X, and the angle increases in the spin direction. The count rate peaks at two angles in the Figure. For one peak (in the vicinity of 1800) the outward normal at I 11S points to the sun. At the other count rate peak the noms] is pointing in the northern hemisphere. ~'here is some change in time of the details of the distributions over the three intervals, but they are generally similar to each other in shape.

5. AN EXI)l.ANA1'lON

In view of the description above of the design characteristics of the HIS, the first question we address is, what is being measured? Or in other words, since the instrument was designed for flyby conditions quite different from those at G-S, why is anything being measured at all? Let us begin with the data far from the comet, before CA. We suggest three possible causes for the non-zero count rate: 1) electronic noise, 2) solar uv photons, and 3) solar wind protons, and consider each separately. While we cannot rule out completely the presence of some electronic noise, we would not expect a signal due only to noise to depend on spin phase, as is shown in Fig. 6. Hence we believe that noise is at most a minor contribution to the measured count rate. Next, the only contribution by solar uv would be due either to direct impingement on the detectors, or from secondary ions released from the spacecraft or instrument surface. The instrument was designed to be solar blind to solar uv so we discard that possible source, Secondary ions emitted from surfaces would be expected to have much lower energies than the 300 eV/e lower cutoff of the instrument response, so we expect no contribution from that source either.

This leaves, finally, solar wind protons. At the speed -400 km/s reported by *Johnstone et al. [1993]*, the energy/charge is -800 eV/e. This is well within the energy bandpass of the HIS, and, as pointed out above, since the AA is a simple electrostatic analyzer, this acceptance is independent of the mass/charge, (We neglect any small mass dependencies of the detector efficiency.) The orientation of the spacecraft and that of the

AA field of view, however, prevent direct access of the solar wind to the HIS entrance aperture. However, the small +-Y component of the solar wind velocity (see below) allows the protons to scatter diffusely off the spacecraft surface, and enter the HIS field of view. The scattering would of course broaden the energy distribution, particularly to energies lower than the incident 800 eV, as seen in the measurements (Fig. 5). It is not clear, however, why the measured distribution extends to much higher energy than the nominal incident energy.

Although the HIS sensor was never calibrated for protons, we can make a rough check on whether this makes physical sense, by simply scaling the heavier ion instrument calibration data with ion energy, a procedure which is approximately correct for the electrostatic analyzer. The count rate measured by HIS can then be estimated as an equivalent incident ion flux of ~4x 10^6 $cm^{-2} s^{-1}$. The total solar wind proton flux at the time of encounter was measured at ~3x 10^8 $cm^{-2} s^{-1}$ by JPA [*Johnstone et al., 1993]*, so the HIS equivalent flux is about 1.3% of the solar wind flux. *McDaniel* [1964] gives about 2% for the scattering efficiency of 800 eV He^+ from a metal surface, and indicates that the efficiency should increase for lighter ions. HIS, of course, measured only a fraction of the scattered flux, but our estimate for proton scattering on the Giotto surface seems to be of the right order of magnitude. We believe therefore that the HIS count rate well before CA is a result of measurement of solar wind protons scattered off the spacecraft (and possibly parts of the instrument) into the sensor.

As Giotto approached closer to G-S, the HIS signal changed only gradually until just inside the inbound bow wave (e.g., Figs. 4 and 5), indicating the continuous detection of protons. The gradual increase in average count rate is presumably due to an increase in the density of picked up cometary ions. We believe these are also protons, from arguments related to the measured energy spectra and the absence of anything above noise levels in the mass analyzer sensor, as noted above. Table 1 shows the equivalent speed range for several ions of likely occurrence at the cornet, using the full 300-1400 eV/e energy/charge range measured by HIS (Fig. 5). For comparison, Fig. 7 shows the ion velocity measured by the JPA sensor from shortly before crossing the BW through CA [*Coates et al.* 1993]. Because the solar wind flow was approximately normal to the magnetic field until quite near to CA [*Neubauer et al.* 1993] picked up ions would be expected to gyrate near 90° to the field with a velocity range from near zero up to twice the solar wind speed. The inset in the lower left of Fig. 6 shows schematically the gyration of a pickup ion in the spacecraft frame. 'l'he bulk flow is to the right, in the -X (solar wind) direction. The minimum occurs at the "turnaround" of the gyration (in the spacecraft frame) and the maximum in the middle of the orbit, The maximum ion energy would thus be expected coming approximately in the -X direction, which corresponds to 180° in Fig. 6. The ions measured at -60° must correspond to those gyrating downward at a lower velocity. For those few cases where the AA data allow explicit energy-azimuth comparison (see Section 2 above) the 180° ions do appear more energetic than those coming from the northern hemi sphere. From Fig. 7, the flow speed is greater than 200 km/s until very near CA. Hence we expect the maximum pickup ion velocity to be about 400 km/s. Table 1 shows that protons are the only ions with a match between the expected pickup velocity and the measured HIS energy range. Heavier ions can be excluded for a second reason, which is their complete absence from the Mass Analyzer. This indicates that no ions at 68 km/s were present, even though Table 1 would require this for water group ions to have been measured by the AA. To summarize, we therefore believe that the HIS Angle Analyzer measured protons throughout the G-S encounter.

6. DISCUSSION

It was noted above (see Figs. 3 and 4) that just inside the BW the HIS count rate took on a very strong, quasi-periodic modulation. In Fig. 8a we show the count rate for the period corresponding to 2×10^4 km before to 1×10^4 km after CA, along with the angle of the magnetic field in the Y-Z plane, arctan (B_z/B_y). During this period B_x is very small, and the field is mainly in the Y-Z plane. Every major peak of the HIS count rate corresponds to a peak in the angle of the magnetic field in the Y-Z plane. The quasi-periodic modulation of the magnetic field was described by *Neubauer et al.* [1993], and ascribed to waves at the water group ion cyclotron frequency (-0.01 Hz). (Note that due to slight differences in onboard data processing between HIS and the magnetometer, there may be -1 s "misalignment" in the times for the two instruments.) The Figure thus indicates that the proton flow direction is strongly modulated by the magnetic field direction. To understand how the HIS measurement relates to the magnetic field direction, refer to Figure 9, which shows schematically the HIS FOV cone and the field orientation for a typical maximum and minimum in the Fig. 8a count rates. "l'he diagram is in the Y-Z plane. At minimum, B_z is very small, and the field lies almost along the Y-axis. In this orientation, if the ions gyrate at their pickup angle of near 90° to the field, they have no direct access to the HIS sensor, and HIS measures only the low count rate due to scattered ions, as described above for the solar wind. In fact, note that the count rate. minima in this region are approximately the same as the count rate level in the solar wind, far from the cornet. The ions would have had to be pitch angle scattered at least the order of 70° in this example for direct access to the HIS sensor. When B_z increases, however, a pitch angle scattering of only about 25° would be needed to enter the HIS FOV. Thus, if the protons had been significantly scattered from their initial -90° pickup angle, we would not expect to see such a strong modulation, so the protons remain in a relatively narrow distribution. In fact, for a typical HIS peak in Fig, 8a, the full width at half maximum corresponds to a field direction change of only about 10°.

Hence we conclude that throughout the G-S encounter, the protons experience very little pitch angle scattering. Note, however, that if the data were averaged over a time period longer than the -90s period of the field variations, this narrow distribution would be smeared out, resulting in the appearance of a much broader distribution in angle. To illustrate this point, panel (b) of Fig. 8 shows the flow velocity components measured by JPA during the same time interval as in panel (a). here, however, the 128 s measurement period is just long enough that any -90 s variations in the flow would be. smeared out, and at the lower time resolution the flow appears smooth. Likewise, the field direction at 128 s resolution would also appear smooth, Hence, although the bulk flow is also probably fluctuating at the -90s period, there is no measurement at that resolution.

Figure 5 indicates that the protons may experience some energy diffusion . The JPA measurements show that from inside the BW crossing to CA the ion flow velocity drops from about 210 to 90 km/s. This range corresponds to energies below the 300 eV/e HIS cutoff for protons, and would not appear in Fig. 5, (See Table 1.) But picked up ions have speeds up to twice the bulk flow speed, as noted above. The -450 eV/e peak in Fig, 5 corresponds to about 300 km/s for protons, and is thus about twice the mean of the JPA range. The exact value of the pickup speed of course depends on the magnetic field orientation, but as mentioned previously, through most of the encounter the bulk flow was near 90° to the field. The peak in Fig, 5 therefore probably represents the protons at the initial pickup speed. Note however that al'bough the energy spectra of Fig. 5 are broad we do not know the actual distribution of the ambient ions because HIS is responding at least in part to ions scattered off the spacecraft, as described above. In addition, because of the energy dependence of the instrument sensitivity, the actual ambient flux is falling off with energy, rather than being flat as indicated by the count rate spectra of Fig. 5.

The behavior of pitch angle distributions for protons at G-S have as yet not been reported, although distributions for water group ions, from JPA measurements, have been described by *Coates et al. [1993]* and *Huddleston et al. [1993],* These results show a considerable pitch angle scattering, as well as energy diffusion, although full isotropy was never reached. It is not clear, however, whether some of the apparent broadening of the distribution may be a result of the 128 s time resolution of the instrument, as discussed above. The behavior of pitch angle distributions for both protons and water group ions outside the Halley bow shock have been discussed by *Neugebauer et al.* [*1990],* based on measurements by Giotto IMS-HERS and JPA. These results show considerable scattering for both ions, although the protons showed much less scattering than the water group ions did. It should be noted also, that in order to improve counting statistics, rather long averaging periods were used in this analysis, so it is not clear whether any high frequency variations in pitch angle were thereby smeared out, as in the case of the G-S JPA results.

Recently, *McKenna-Lawlor et al. [1993]* reported on measurements of energetic ions at G-S. Their results show a very strong modulation of ion flux above -260 keV energy, dependent on magnetic field direction. They also suggest that the modulation is a result of a narrow pitch angle distribution sweeping past the instrument field of view as the field direction oscillates at the water group ion frequency, in agreement with our conclusion about the protons. What is surprising is that this phenomenon covers such a wide ion energy range: from superthermal to hundreds of keV.

Another recent report by *Rème et al. [1993]* describes similar modulations in the electron flux measured at G-S. However, they do not give any physical explanation for the data, but convert the flux to an equivalent time (and therefore space) varying electron density. These would correspond to spatial "packets" of significant electron density enhancements of the order of -100 km in extent. This appears physically unrealistic,

Although most, if not all models of comet ion pickup predict rapid pitch angle scattering of protons mediated by the generation of waves at the proton ion cyclotron frequency (see e.g. the review by *Gary,* [1991], and more recently the work by Ye et al., [1993]), these waves have been elusive. Recent reports (*Mazelle et al., [1993]* and *Tan et al., [1993])* show that at best the proton ion cyclotron frequency waves are very infrequent and/or extremely weak. Gary et al. [1988] have suggested that the waves dissipate rapidly in [he energy transfer process, and are therefore expected to be present at very low amplitude. *Tsurutani [1992]*, however, by comparison with the case at the Earth's foreshock, has rejected this idea,

Before leaving this discussion, three points should be made about the physical conditions at G-S at the time of the encounter, which have an impact on scattering processes, and which are significantly different from conditions during the Halley and Giacobinni-Zinner (G-Z) encounters. First, as noted above, through most of the encounter the bulk flow was near *90°* to the magnetic field. *Gary et al.* [1989] predict lower wave amplitude for this case, although the proton cyclotron waves are certainly weak, if present, for Halley and G-Z, where the angle to the field was generally much smaller most of the time. Second, the gas production rate at G-S at the time of encounter was about two orders of magnitude less than that at the Halley flyby and about one order less than at the G-z encounter. Thus the scale sizes of any density-dependent processes were also correspondingly smaller at G-S, and consequently the time available to "process" the plasma as it flowed through the G-S environment was shorter, Third, the ambient magnetic field strength in the vicinity of G-S at the time of encounter was considerably greater than at Halley and G-Z, so ion cyclotron frequencies were higher and gyroradii smaller. This last effect may have compensated partly for the second effect.

A last point is a speculation on the interpretation of the marked asymmetry in the modulation in the measured count rate relative to CA shown by Figs. 3 and 4. Although the field direction in the Y-Z plane continues to oscillate beyond CA (cf. Fig. 8a), examination of the details show that the nature of the field components is asymmetric relative to CA (*Neubauer et al., [1993])*. In particular, B_x increases slightly while By decreases. In addition, the waves become less coherent after CA, Further, the bulk plasma flow is also asymmetric in direction relative to CA. Of particular note is that it diverts about 20° away from the nearly -X direction before CA. This may cause sufficient scattering of the protons so they no longer have as narrow a pitch angle distribution as before CA, and thus do not produce. as strong a modulation in HIS.

7. SUMMARY AND CONCLUSIONS

We have presented the results of the measurement of ion fluxes at 4 s resolution by the HIS sensor of the Giotto Ion Mass Spectrometer throughout the flyby of comet P/Grigg-Skjellerup on July 10, 1992. We have shown that the measured ions are most probably protons, although the sensor was not originally intended for detecting these ions. The strong modulation of the fluxes at the water group ion cyclotron period (-90 s) correlates well with the variation in the magnetic field direction. From an examination of the field direction relative to the HIS field of view, we conclude that the modulation results from a narrow pitch angle distribution of the protons being swept back and forth across the sensor. A further conclusion from this, is that the protons experienced very little pitch angle scattering, even close in to the comet. This implies a paucity of waves (for whatever reason) at the proton cyclotron frequency which would have been expected to produce the scattering, Hence, as seen in Fig. 8a, the protons "ride along" with the lower frequency of the water group waves. Of interest, is a recent report on the measurement of energetic ions at G-S (*McKenna-Lawlor et al.*, [1993]), which is in agreement with this conclusion of narrow pitch angle distributions.

In contrast, previous reports of water group ion pitch angle distributions from the Giotto JPA sensor (e. g., *Coates et al., [1993]*) have shown that these heavier ions are considerably scattered, although are far from isotropic. However, if the distribution were indeed narrow, the longer (-128 s) measurement period used by JPA might have caused some time aliasing and smearing.

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Figures

1. Schematic of IMS-HIS angle analyzer (AA) field of view relative to the Giotto spacecraft.

2. Giotto trajectory in comet-sun-ecliptic (CSE) Y-Z plane, showing relation to HIS AA field of view. "l'he +X direction, which is toward the sun, is into the page.

3. 111S AA counts/spin, --260,000 to +86,000 km relative to comet close approach (CA). The corresponding spacecraft event time (SCET) in UT is given at the top of the plot.

4. HIS AA counts/spin, --20,000 to +20,000 km relative to CA. SCET is given at the top. BW = inbound "bow wave", BS = outbound bow shock.

5. Energy spectra for the 3 periods: -260,000 to -145,000 km (10:08:41 to 12:26:09 SCET; solid line), -145,000 to -24394 km (12:26:09 to 14:49:39 SCET; dashed line), and -19,900 to 25,300 km (14:54:59 to 15:48:51 SCET; dotted line) relative to CA.

6. Azimuth (spin plane) angle dependence of AA count rate for the same three intervals as in Fig. 5. The inset in the lower left is a schematic representation of gyrating pickup ions being swept past the spacecraft by the solar wind bulk flow. (See the text for discusion of this.)

7, Plasma flow velocity measured by the Giotto JPA sensor (CSE frame).

8. a) Comparison of HIS AA count rates and angle of magnetic field in the CSE Y-Z plane for a short period of time near CA; b) Velocity components of plasma flow as measured by the JPA instrument for the same interval. The symbols mark the individual measurement points. The interval corresponds to distances of about 24,100 krn before to 9,400 km after CA.

9. HIS FOV relative to the magnetic field direction at a typical maximum and minimum HIS AA count rate in the CSE Y-Z plane. (See Fig. 8a.)

Mm/Charge (amu/e)	Velocity Range (km/s)
1	240-520
4	120-260
16	*60-130*
19	55-120

Table 1, Velocity ranges corresponding to the 300 to 1400 eV/e energy/charge acceptance of the HIS angle analyzer for different solar wind and cometary ions.

SCHEMATIC OF IMS-HIS ANGLE ANALYZER FIELDS OF VIEW

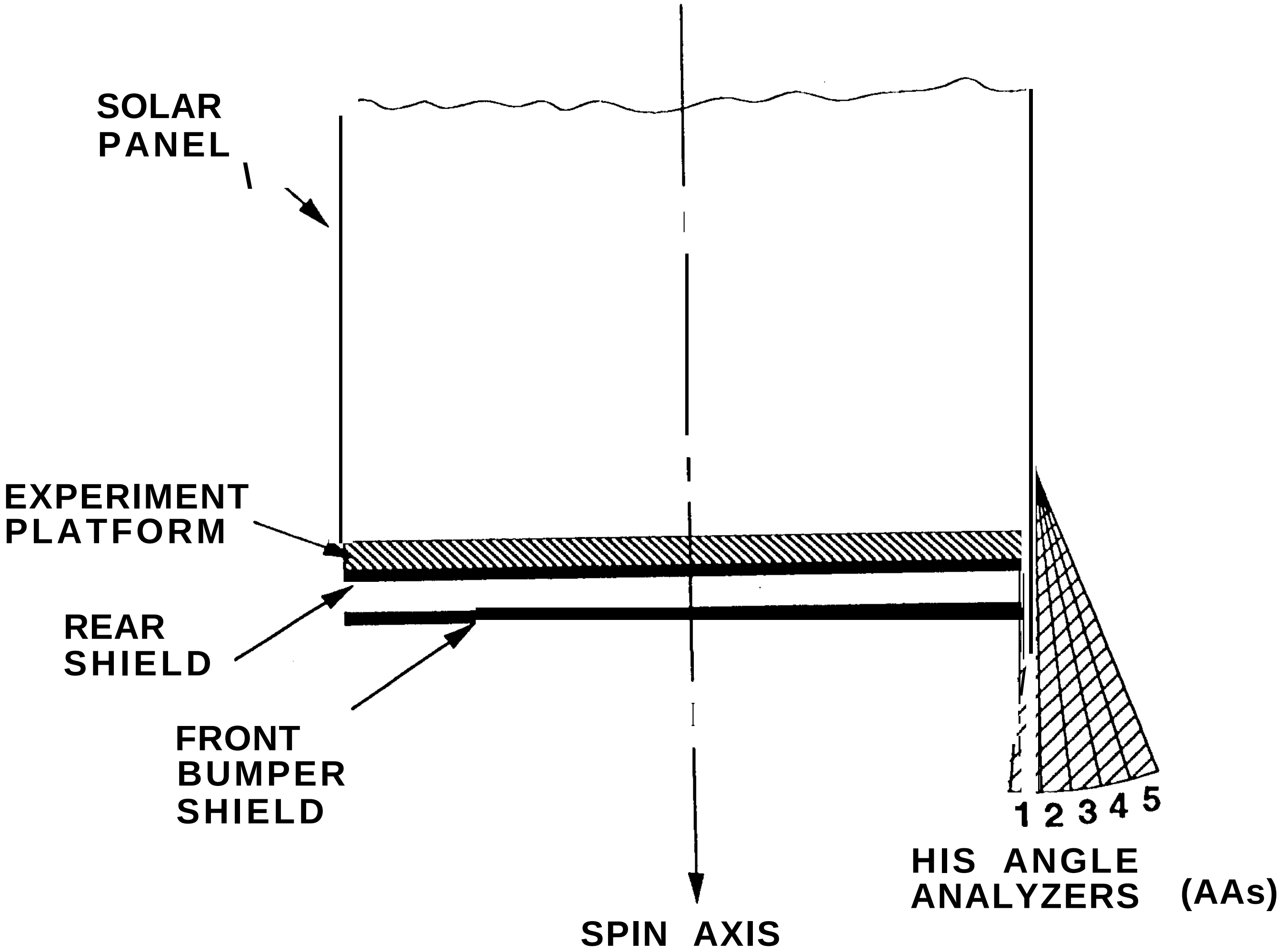


Fig. 1

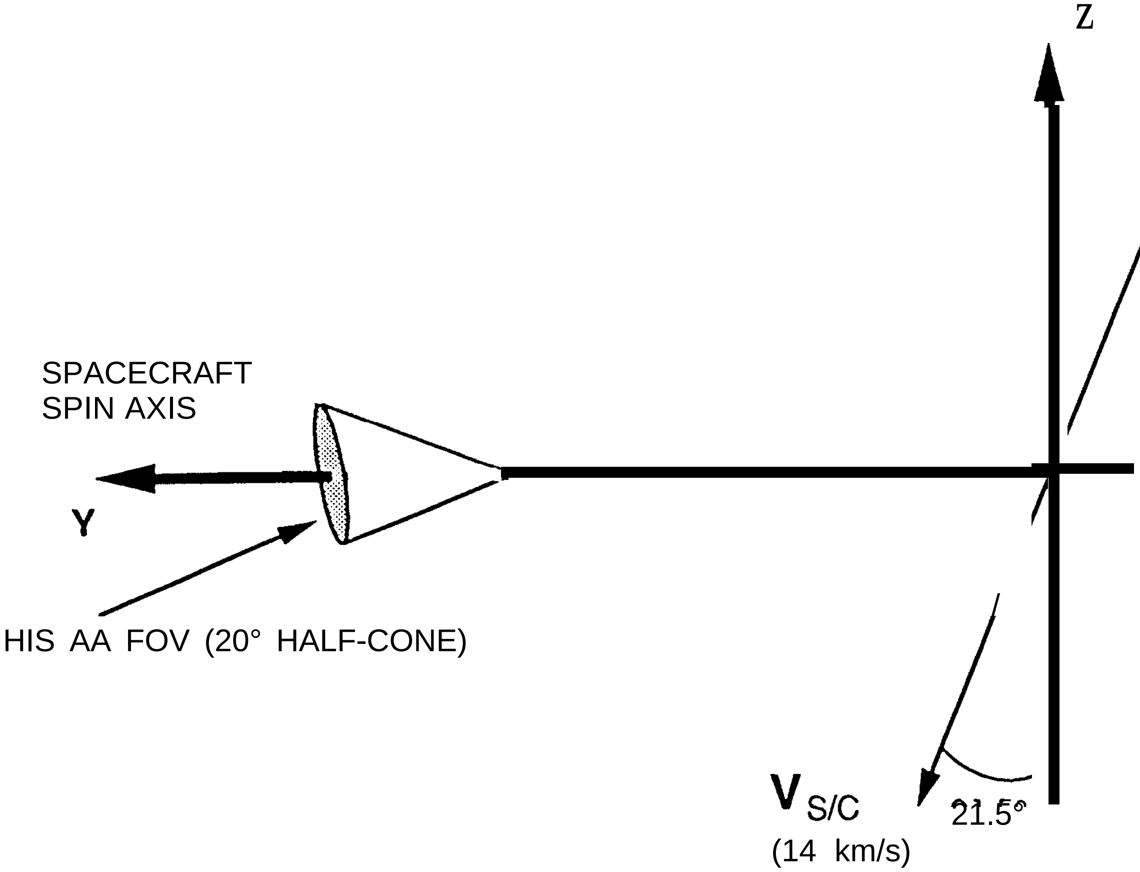


Fig. 2

TOTAL HIS AA COUNTS/SPIN

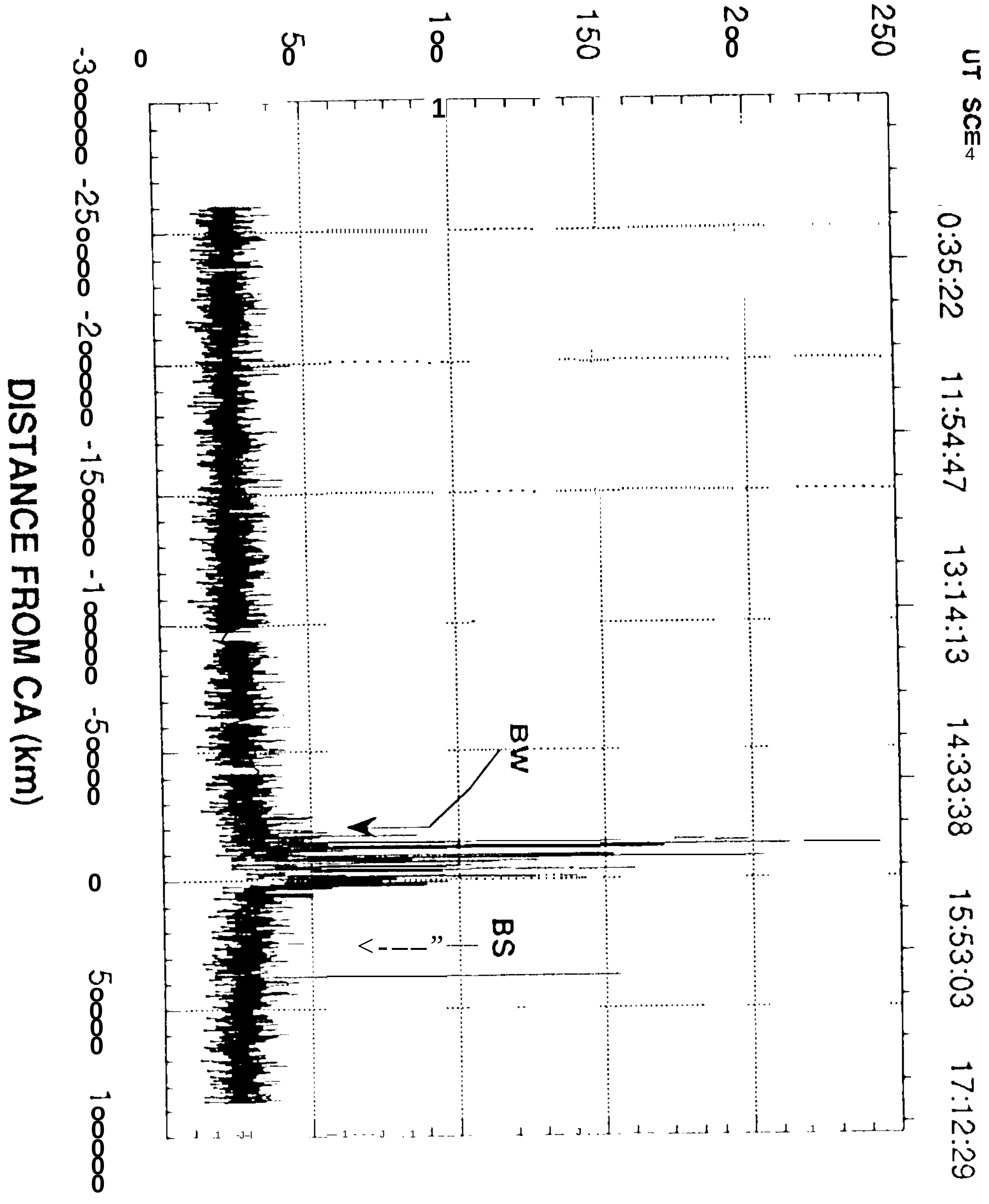


Fig. 3

TOTAL HIS AA COUNTS/SPIN

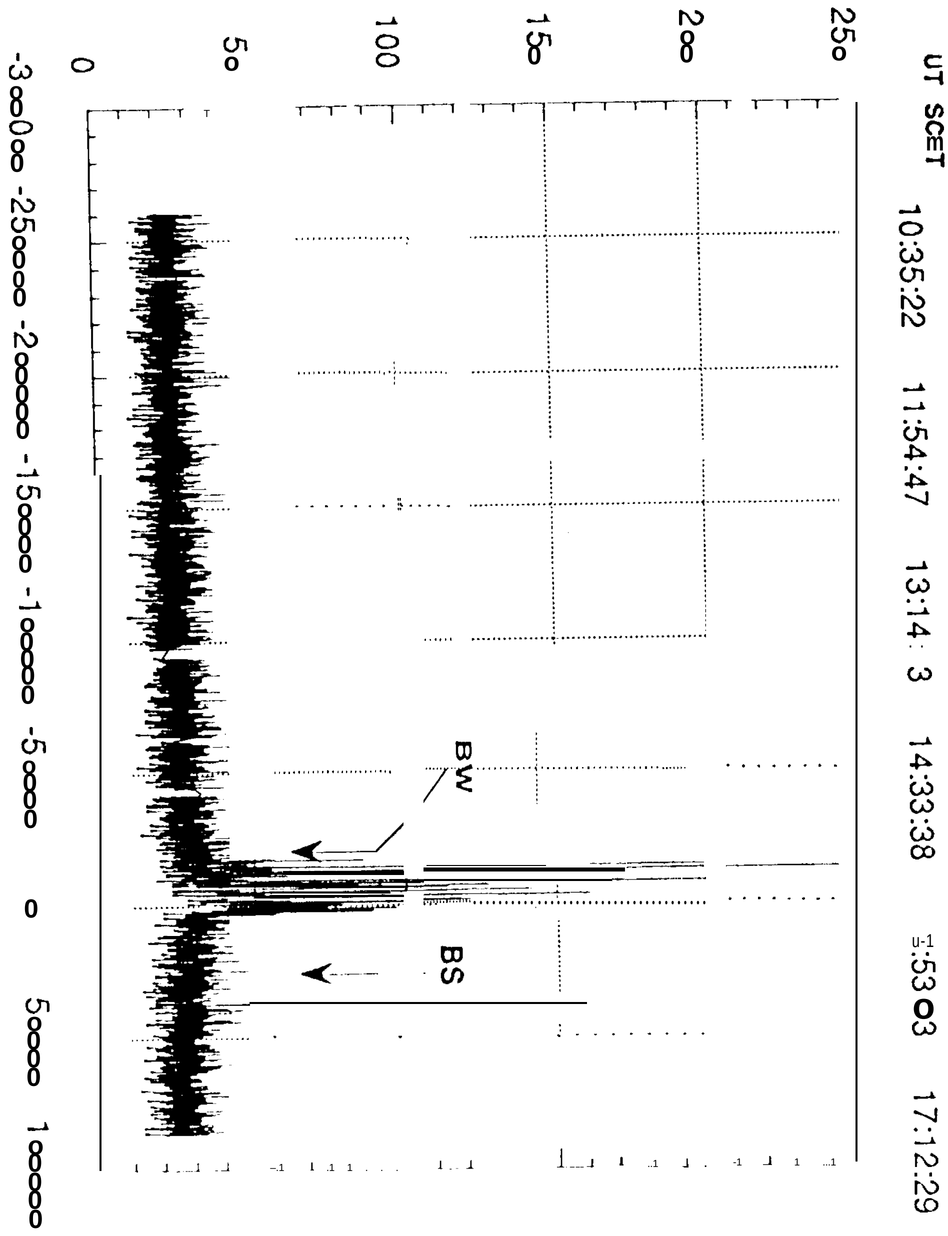
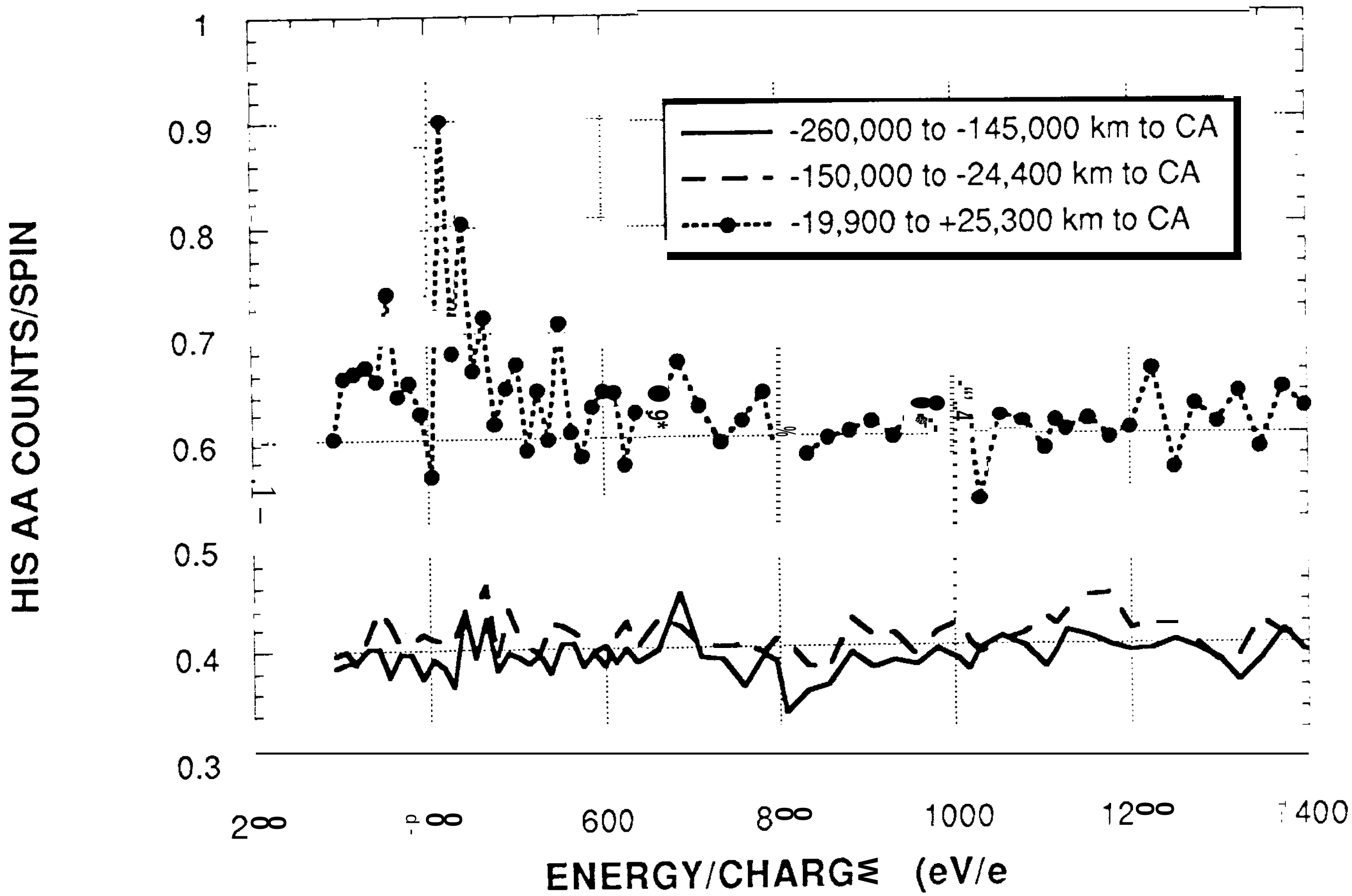
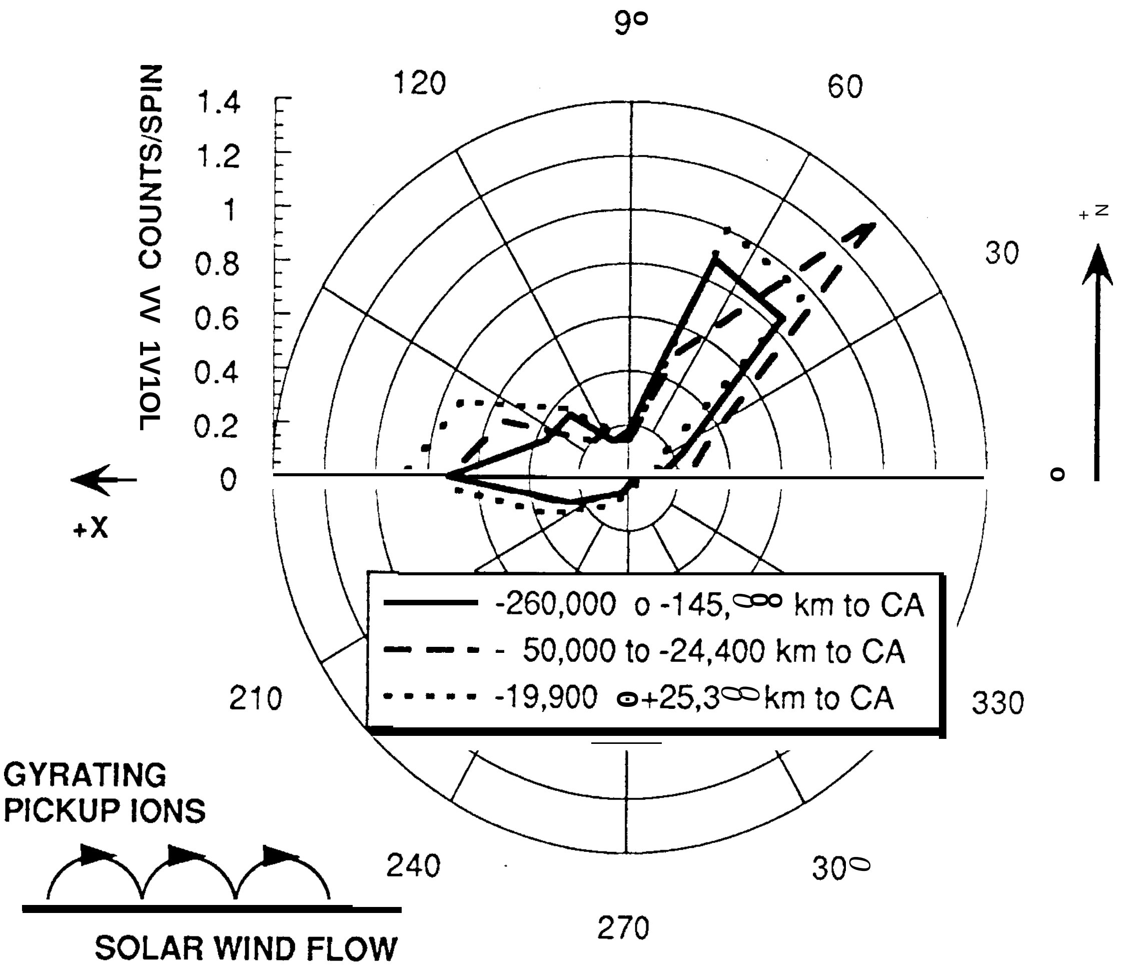


Fig. 3



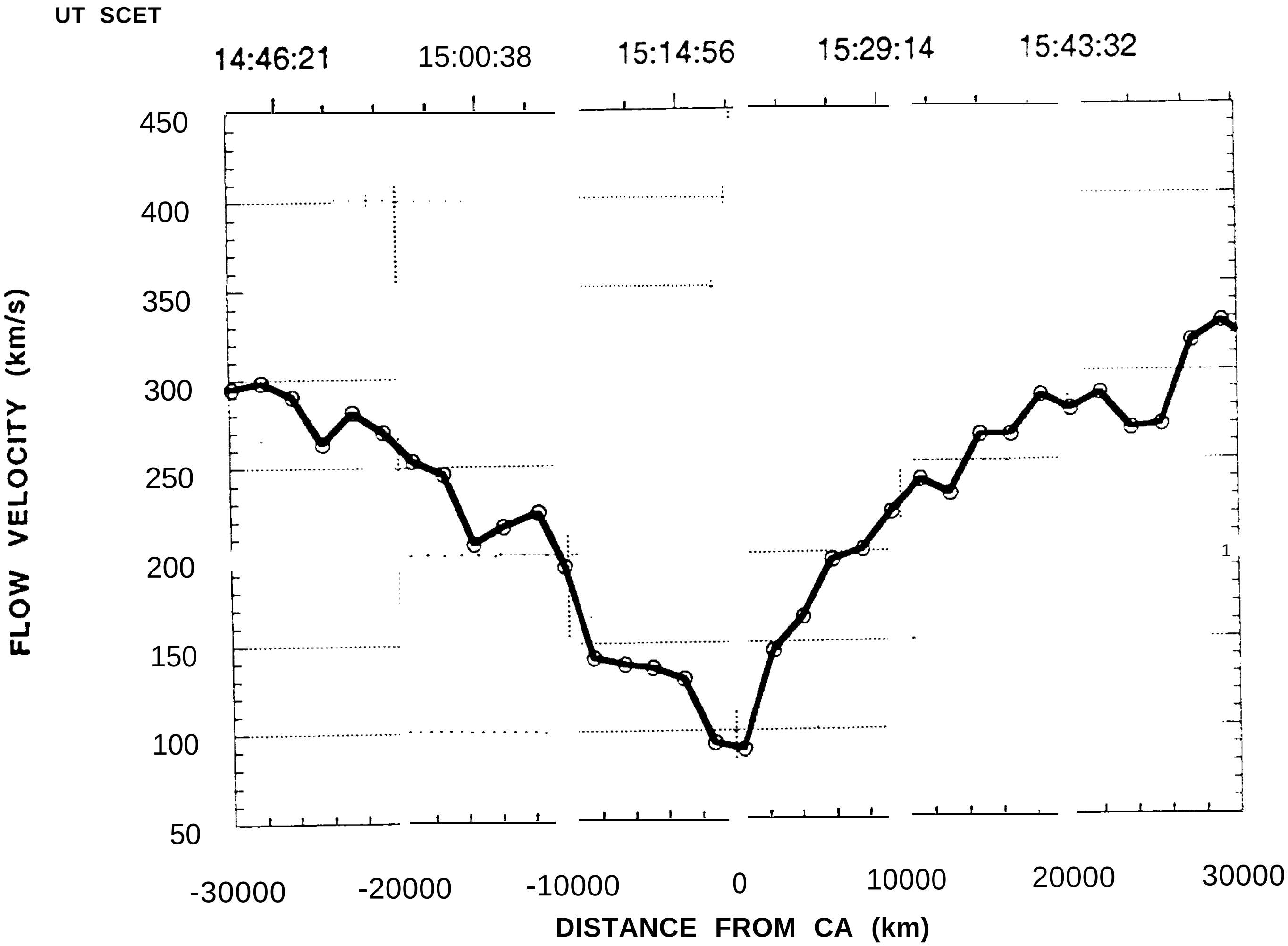
HIS AA COUNTS/SPIN
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
200
400
600
800
1000
1200
1400
ENERGY/CHARGE (eV/e)
-260,000 to -145,000 km to CA
-150,000 to -24,400 km to CA
-19,900 to +25,300 km to CA

Fig. 5



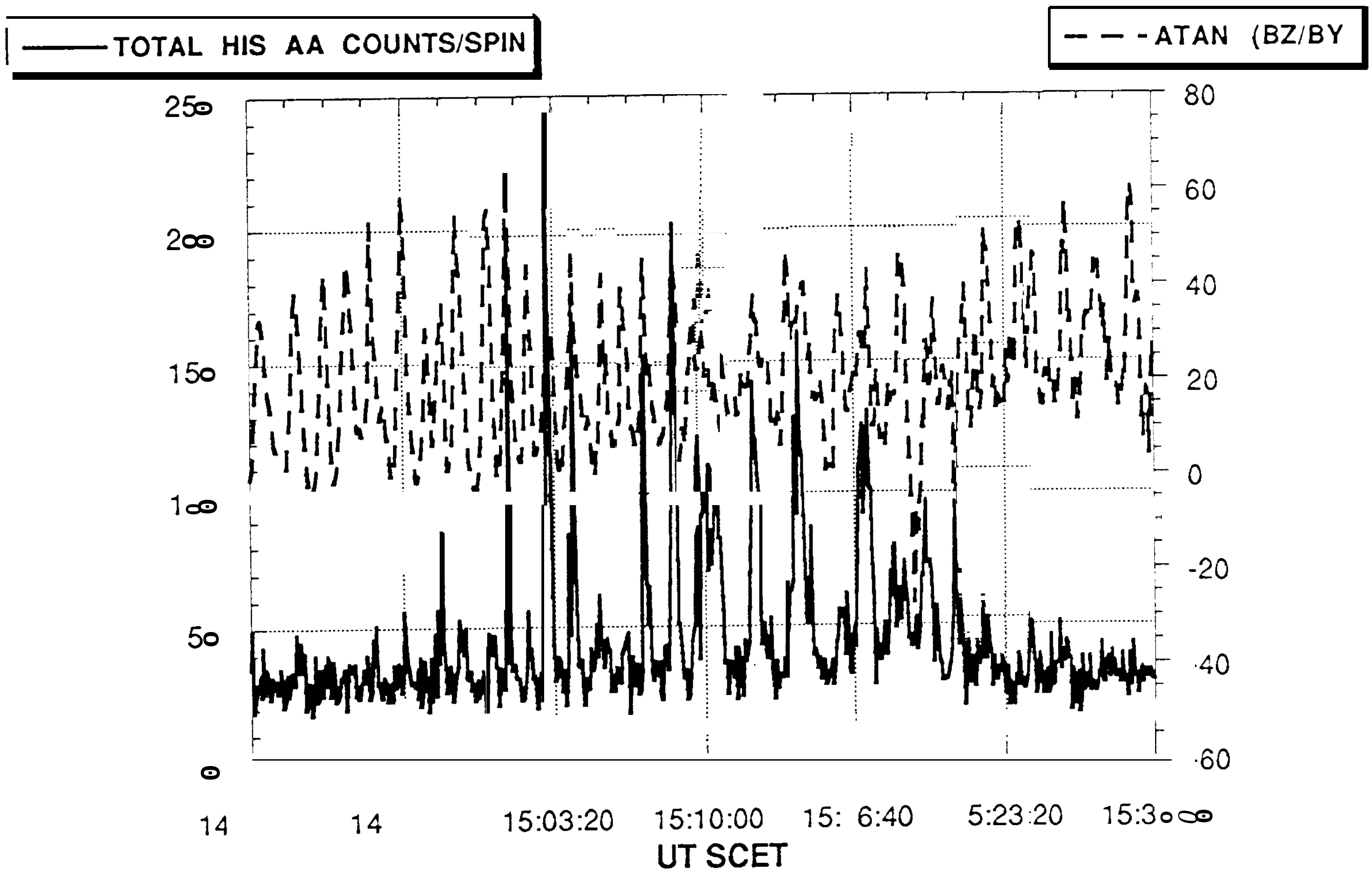
9o
120
60
30
0
+Z
+X
TOTAL VV COUNTS/SPIN
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-260,000 o -145,000 km to CA
- 50,000 to -24,400 km to CA
-19,900 o+25,300 km to CA
210
330
240
300
270
GYRATING
PICKUP IONS
SOLAR WIND FLOW

Fig. 6



UT SCET
14:46:21
15:00:38
15:14:56
15:29:14
15:43:32
450
400
350
300
250
200
150
100
50
FLOW VELOCITY (km/s)
-30000
-20000
-10000
0
10000
20000
30000
DISTANCE FROM CA (km)

Fig 2


TOTAL HIS AA COUNTS/SPIN
ATAN (BZ/BY
250
200
150
100
50
0
80
60
40
20
0
-20
-40
-60
14
14
15:03:20
15:10:00
15: 6:40
5:23:20
15:3000
UT SCET
Fig. 8a

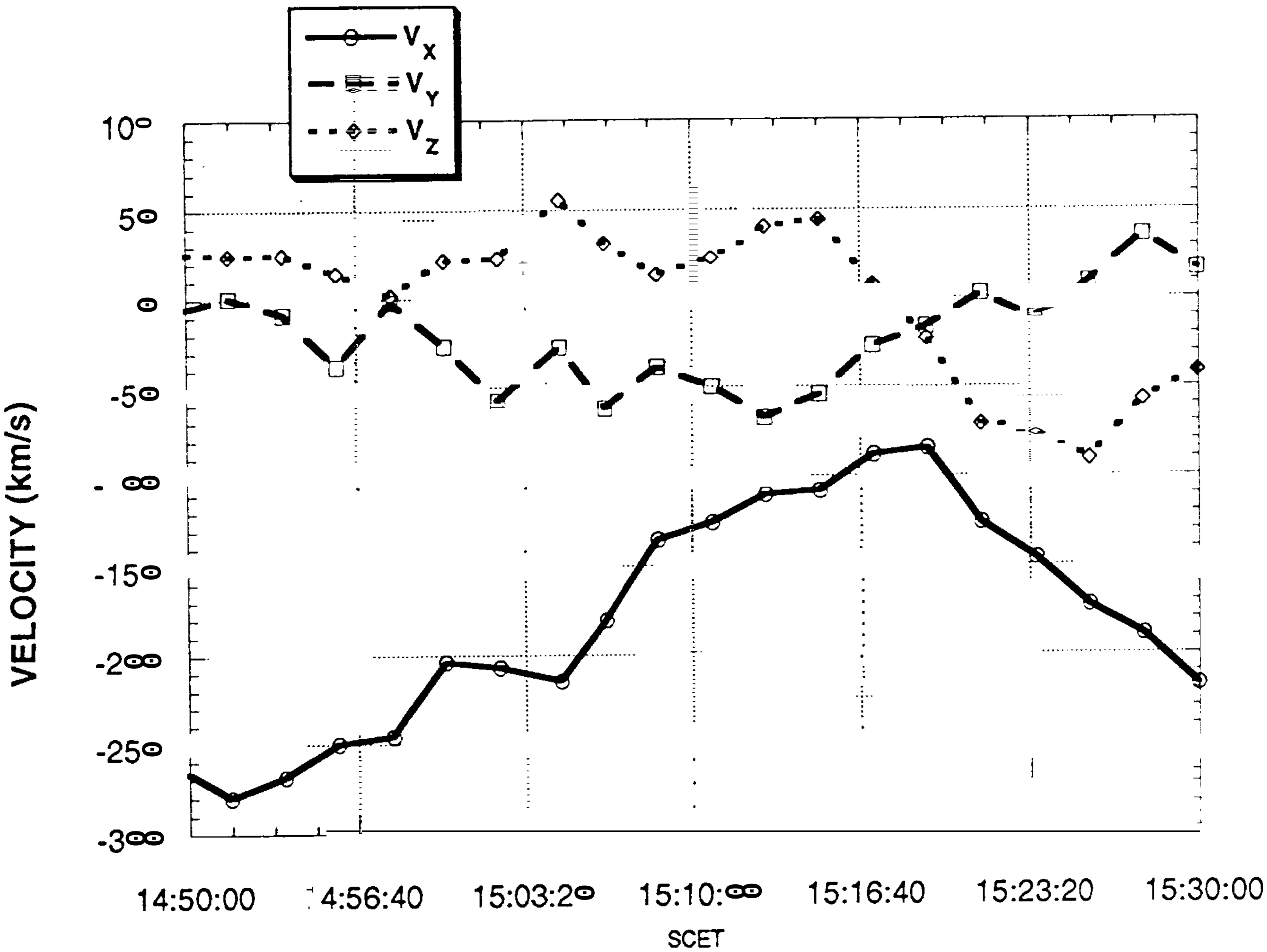
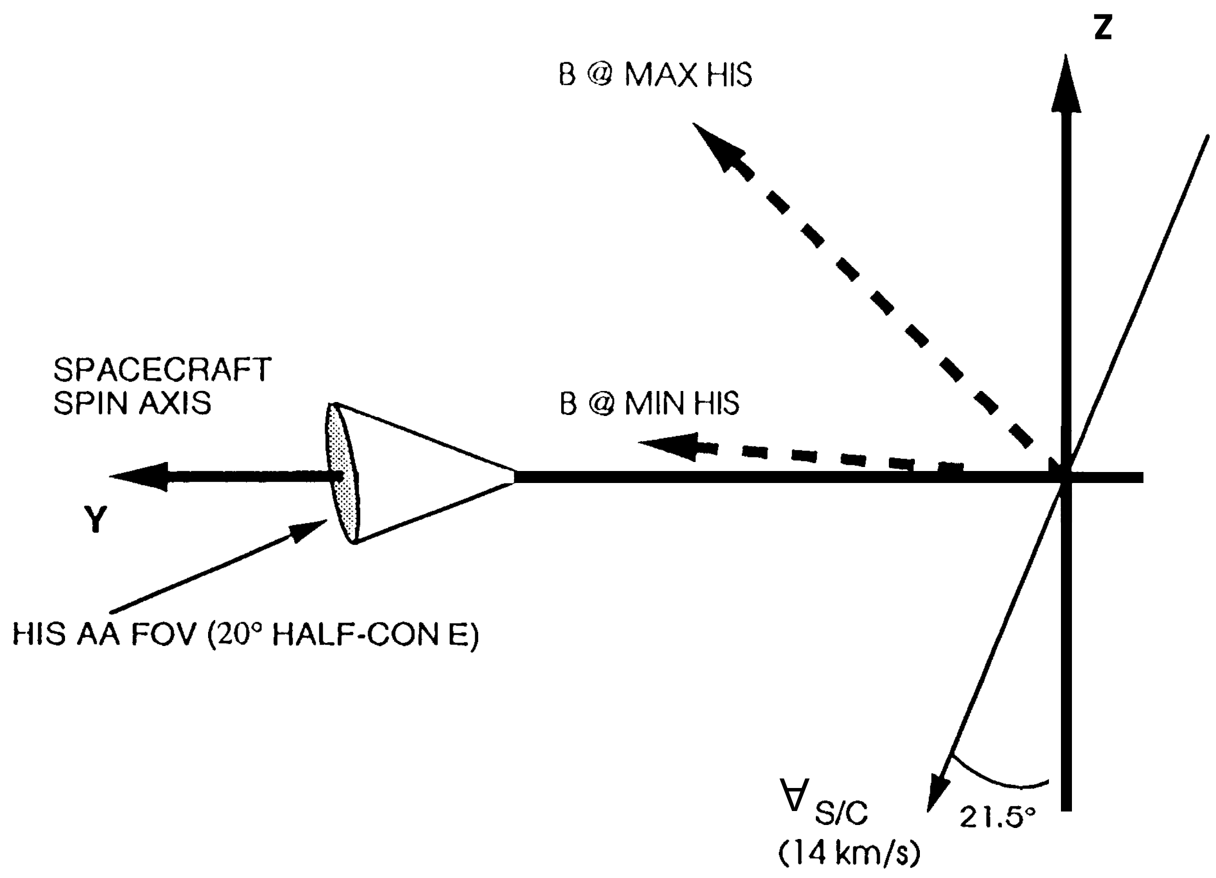

V_X
V_Y
V_Z
100
50
0
-50
-100
-150
-200
-250
-300
VELOCITY (km/s)
14:50:00
14:56:40
15:03:20
15:10:00
15:16:40
15:23:20
15:30:00
SCET

Fig. 8b



Z
B @ MAX HIS
SPACECRAFT
SPIN AXIS
B @ MIN HIS
Y
HIS AA FOV (20° HALF-CON E)
$V_{S/C}$
(14 km/s)
21.5°

Fig. 9